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SOME FURTHER EXPERIMENTS IN STREET LIGHTING

BY

S. ENGLISH, D.Sc., F.I.C., F.Inst.P., and E. STROUD

(Research Laboratories, Holophone, Ltd.)

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Some Further Experiments in Street Lighting

by S. ENGLISH, D.Sc., F.I.C., F.Inst.P., and E. STROUD

AT the last meeting of this Association in Cheltenham one of us, when joining in the discussion of a paper presented by Professor Van der Verffhorst, made a plea for a more open mind on the two questions;—what was good street lighting? and how was such street lighting best obtained? The Continental view seemed to be diametrically opposed to the British view, but it seemed inconceivable that these two views of this problem could be so wide apart as appeared at first sight.

Recently an attempt¹ was made to take an unbiased view of the real purpose of street lighting and the characteristics of a good street lighting installation. It was pointed out that the aim of street lighting was not to produce uniform illumination along the roadway, though this in itself may be excellent, especially where matt road surfaces or stone sets are concerned; it was not to produce high road surface brightness, though this was, within limits, a valuable feature; it was not to eliminate all glare, though this also appeared a desirable feature; neither was it to produce a uniform glare irrespective of the angle subtended at the eye level by the light sources, though this had certain definite advantages. None of these features individually produces good street lighting, but a suitable combination of them and other points that have not been mentioned, does. When this ideal street lighting is obtained it will not be judged by reference to any of these factors, but by the ability to see clearly, distinctly and easily along the roadway, in much the same way that one does not judge a motor car by the size of its engine, —by its carburettor,—its tyres, or the weight of its body,—or any other single feature, *but by its performance on the road.*

Visibility

Following up this argument, we suggest that the real reason for street lighting is to enable road users of whatever class they belong, to see clearly and easily whatever they need to see, and more particularly to see obstacles or conditions that may lead to danger. Keeping this in mind as the final test of good street lighting, it is obviously necessary for street lighting engineers so to combine the various factors that affect visibility on lighted road-

ways at night time in such a way as to produce the best possible degree of visibility, consistent, of course, with reasonable installation, running and maintenance costs. To assist in this, it is necessary to have some means of measuring the visibility itself. For this, various instruments have been suggested from time to time, but in our opinion none of these instruments actually measures visibility. To give satisfactory results it is obvious that the actual visibility of objects on the lighted roadway must be determined, and the eye must be functioning under the conditions imposed by the lighting installation without any modification. For this reason it is not possible to use an *instrument which shields the eye from any glare that may be present or which limits its field of view to a restricted area or areas of the roadway.* Some of the instruments which are alleged to measure visibility do nothing more than measure the apparent brightness of the road surface, and anyone who pretends that such measurements in themselves bear any relation to actual visibilities, ignores several very important factors. For these reasons we have come to the conclusion that visibilities must be determined by the unaided eye in just the same way as obstructions are ordinarily seen on lighted roadways.

When we consider the processes that are involved in the seeing of an object on the roadway—first becoming aware of its presence and later its recognition—there are numerous factors involved; some such as size, colour and movement are, as it were, personal to the object itself; others, such as its apparent brightness, the brightness of the road surface, the general surrounding illumination, and any glare that may be present are more concerned with the lighting installation. It is factors of the latter group that street lighting engineers have to consider, and by judicious compromise weld them into a satisfactory lighting scheme. These various factors are not all of equal importance, nor are their relative importance constant in differing neighbourhoods or on different types of roads. For example, in towns where the appearance of the buildings lining the streets is of importance and where pedestrian requirements must be considered, the general illumination permitting people and things to be seen by direct vision is a matter of primary importance, while silhouette vision enabling objects to be detected at a distance, though necessary, becomes a matter of secondary importance. Along

¹ Trans. I.E.S. (London). Vol. II, No. 6, 1937, p. 68.

main roads in between towns, pedestrian traffic is negligible and the needs of fast moving motor traffic must be met by providing conditions favouring silhouette vision. Easy silhouette vision, like direct vision, requires a difference in brightness between two objects or surfaces, in order to distinguish one from the other. Naturally, other things being equal, the greater this contrast between the relatively dark object and the lighter background of road surface, the easier it is to see the object. This contrast may be enhanced by projecting the light from the road lighting fittings in such a way as to ensure that sufficient light is reflected from the road surface towards the observer to raise the apparent brightness of the roadway. Now, even though road surfaces be relatively rough, they possess "mixed reflection" properties, i.e., they reflect some light specularly and some diffusely, and as is well known in such cases, the proportion of light specularly reflected increases as the angle of incidence of the light on the surface increases.

Road Surface Reflection and Glare

Quite a number of investigators have measured the reflection factor of specimens of road surface, but the ordinary reflection factors are not of much assistance when considering the apparent surface brightness of a roadway, since ordinarily the useful angle of view of the roadway is substantially constant and is in the neighbourhood of 0 to 3° below the horizontal. It is possible, however, to replot some results given by Taylor¹ so as to show the proportion of light reflected by a dry tar macadam road surface in a direction 87° from the vertical from light which is incident at angles of from 60° to 88° from the vertical. This curve which is shown as "B" in Fig. 1 indicates quite clearly that the apparent brightness of a dry macadam surface when viewed at 3° below the horizontal only increases quite slowly until the light is incident on it at angles exceeding 83° from the normal, and that the surface brightness increases very quickly when light is incident at from 85° to 88° from the normal. Light incident on a road surface at these angles therefore materially helps in building up brightness contrasts, and would at the same time assist visibility were it not for the fact that the glare simultaneously produced by these high beams reduces the sensitivity of the eye to such an extent as to destroy completely any advantage gained by the increased brightness contrasts.

Evidence on this point is obtained by considering some results given by P. W. Cobb and F. K. Moss² dealing with the reduction in visibility produced by glare, when a constant intensity glare source is

operative at various angular distances above the line of sight. Their results are given as the degree of contrast that is necessary to enable objects to be identified under the various "glare" conditions. Their results for the lowest background brightness that they investigated are plotted as curve "G" in Fig. 1. This curve indicates that glare does not seriously impede vision until the angle between the glare source and the line of sight is less than 15°, or in street lighting until the light reaches the eye at angles exceeding 75° from the vertical.

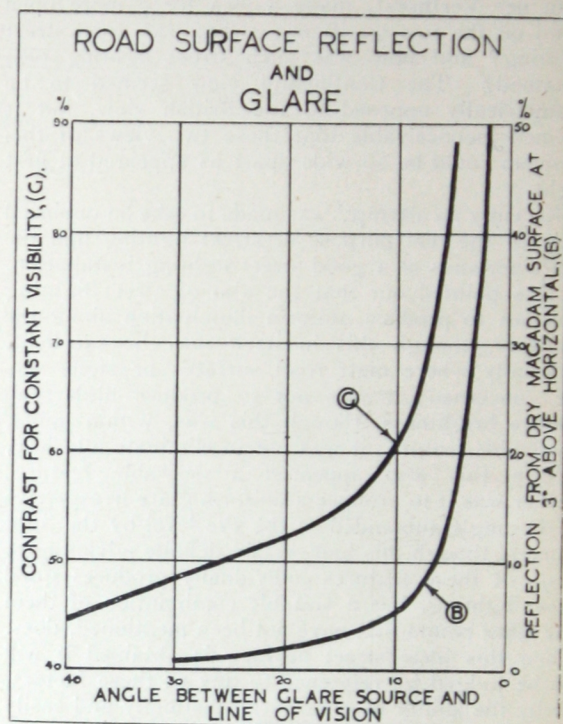


FIG. 1.

Comparison of these two curves "B" and "G" shows quite clearly that glare ("G") becomes detrimental to vision at distinctly lower angles than the road reflection ("B") becomes really effective in producing a high surface brightness. This is well known among street lighting engineers, but in view of the idea that has been disseminated recently that glare does not matter when the road surface has a high brightness value, it was thought desirable to confirm these theoretical considerations by amplifying some preliminary observations that were made on this point some time ago.¹ For this purpose an experimental model road—on a 1-5th scale—was used.

¹ Proc. I.C.I. 1928. p. 53.

² I.C.I. 1928. Paper 9, p. 5.

¹ Loc. cit.

Model Road Tests

The model road was 100 feet long and by means of a large plate glass mirror at one end its apparent length was doubled, and corresponded to an actual road length of 333 yards. The carriageway was 7 feet wide (corresponding to 35 feet), and was flanked by two pathways of dark stone colour, each 1 foot wide (corresponding to 5 feet). The surface of the model road was dark grey asphalt, having a reflection factor of 8%, and corresponding to an ordinary unpolished road surface. Five small lanterns were carried at a filament height of 4 feet $2\frac{1}{2}$ inches, and at a spacing of 25 feet, corresponding to 21 feet and 125 feet respectively, and giving a spacing height ratio of 6/1. The lanterns were fitted with 40-watt ring filament, clear bulb lamps housed in non-axial asymmetric 7-inch dome refractors,

in diameter, was provided with a projection one inch square at a point on its periphery. It was mounted on a shaft and spun, the projection coming to rest in one of the twelve positions represented by the hours on a clock face. The disc and its projection were painted a dark matt grey and had a reflection factor of 8% corresponding fairly closely to the average reflection factor of the relatively dark clothes worn by most men. The disc was placed in turn on each of the 15 regularly spaced spots referred to above, and was observed from a point two feet behind the first lamp and one foot nine inches from the near side kerb, i.e., quarter of the way across the carriageway. For these observations the eyes were kept by a gauge at 12 inches from the ground, corresponding to 5 feet on an ordinary road. The area covered by the observations extended from

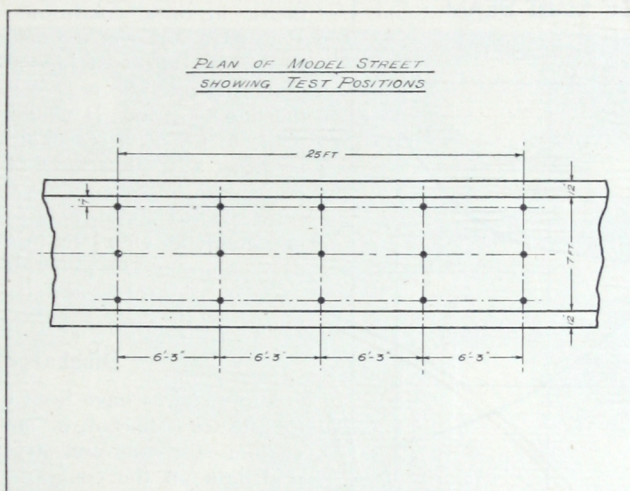


FIG. 2.

arranged in staggered formation with an overhang of 1 foot (corresponding to 5 feet from the kerb).

For the present series of tests everything was kept constant except the angle of the centre of the beams given by the refractors, which was varied by steps of 5° , beginning at 70° from the vertical and passing on to 75° , 80° and 85° . At each of these beam inclinations the following series of readings and observations were made:—

(1) Illumination readings were taken at 15 regularly spaced points between the third and fourth fittings from one end, and also at the two B.S.S. test points, as indicated in Fig. 2. From these readings diversity ratios were calculated and isolux diagrams showing the spread of illumination over the roadway were prepared.

(2) The visibility along the roadway was measured in the following manner. A brass disc, five inches

52 feet to 77 feet from the observer, corresponding on a full scale road to 87 and 128 yards respectively. It may be argued that this distance is rather short, and that a motorist, when travelling at a reasonable speed, focusses his eyes further ahead, but it may also be argued that more accidents happen because of pedestrians stepping off pavements not far in front of cars, or because cyclists come out of side roads just as cars are approaching the junctions, than occur because a driver could not see clearly a quarter of a mile ahead. For the avoidance of accidents of this nature, it is essential that visibility in the neighbourhood of the nearside kerb, at relatively near distances, should be good.

A measure of the visibility at each point was obtained by spinning the disc for a moment and then when it had stopped, if it was possible to see the projection, the observer made a note of its

position (by reference to a clock face). The operator, who was close to the disc, also made a note of its position. Ten such observations were made at each of the 15 test spots, and the results summarised so as to indicate separately the visibilities along the near side of the road, along the middle and along the off side, and also the percentage visibility over the whole area. A full set of such measurements was made in each set of tests with the units exposed to view as in ordinary practice, a similar set of readings was then taken, but with the light sources screened from view so as to eliminate all possibility of glare.

The results are set out diagrammatically in Fig. 3, in which it is clearly seen that the visibility with the screened sources continues to rise as the angle of

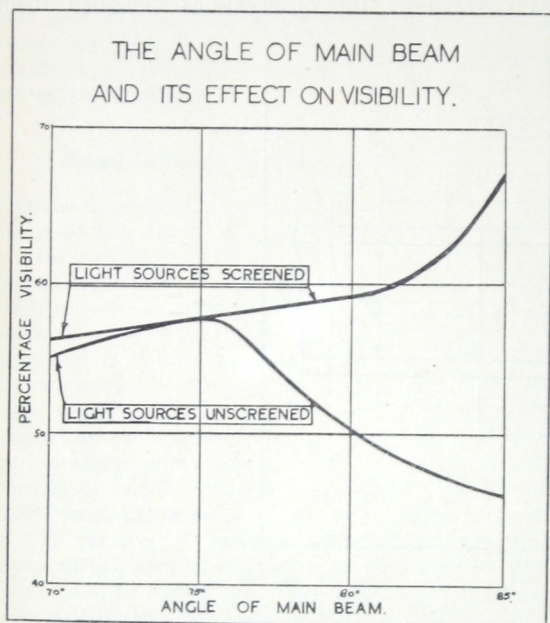


FIG. 3.

the main beam is increased, as would be expected from the greater contrast produced by the higher angle beams, but when considering the normal lighting, i.e., without a screen in front of the eyes, the percentage visibility rises a little on passing from 70° to 75°, but falls again on passing to 80°, and falls still further on passing to 85°. Comparison of the two curves shows that for main beams at 70° and 75° the visibility is unaffected by the presence of a shield cutting off the view of the units, but with main beams at 80° there is a reduction of visibility due to glare of 9%, and at 85° a corresponding reduction of 21%. It is obvious, therefore, that in the tests with the light sources exposed, the effect of the high angle beams in building up strong

contrasts was more than counterbalanced by the glare that was concurrently produced (see Fig. 4). The curves also confirm what has been found by practice over many years, viz., that the best compromise between these two conflicting phenomena is obtained when the main beams are directed along the roadway at 75° to the vertical, and that strong beams above this angle are detrimental to good visibility.

It is just possible that, if our roads were perfectly straight and level, it might be feasible to direct light from fittings at, say, 1° to 2° below the horizontal, and thereby produce very high surface brightnesses and consequent strong contrasts, without producing excessive glare, for as is well known in street lighting, glare is proportional to the foot-candle intensity at the eye. This is reduced rapidly as the distance of the source is increased, being inversely proportional to the square of the distance, while the glare factor in these conditions increases approximately as the 3/2 power of the distance. That is, for distant lamps, the effect of increased distance is to reduce glare, despite the nearer approach of the source to the line of sight. It would, therefore, appear worth while to try on a reasonably straight and level road to direct a beam of light at from 1° to 2° below the horizontal, and then have a zone of reduced intensity from 88° to about 77°, followed by another beam maximum at 75°. In this way it may be possible to combine good general illumination, high road surface brightness and comparative freedom from glare.

Discharge Lamps

Many claims have been made regarding the value of electric discharge lamps—both mercury and sodium—for road and street lighting, but very little real data on the comparison of these two sources between themselves and against filament lamps has found its way into the technical Press. Many photographs have been published, but since discharge lamps give a much bigger lumen output than filament lamps of corresponding wattage they naturally make roads and streets appear better lighted. In addition to this increased light output, new installations using these lamps generally employ a distinctly smaller spacing-height ratio than was employed in earlier installations that they may have replaced, thus again tending to give distinctly better effects. For both these reasons, "before" and "after" photographs, even if untouched in every sense of the word, possibly tend to give an exaggerated impression of improvement produced by the change over from one type of lamp to another. Without in any way wishing to minimise the advantages of these new lamps, it is felt that it would be most useful to road lighting engineers to have a full series of tests of the qualities of road lighting, and naturally including visibility tests, given by filament, mercury

and sodium lamps (a) of equal wattages, and (b) of similar lumen output, each type of lamp being housed in suitably designed fittings, but otherwise used as far as possible under identical conditions. At the present time it is impossible to carry out such a scheme of tests exactly, but so far as lamp limitations permit, a start has been made on this work.

For a comparison of this nature, using various types of discharge lamps, work on a small scale model road is, of course, impossible. We were, therefore, very fortunate indeed in having a street

corresponding to those used on the model road, and shown in Fig. 2—the B.S.S. test points were also marked. Exactly similar tests to those made on the model and described earlier were carried out on this test stretch of roadway, the position of observation in the visibility tests and for photographs being one-quarter of the way across the road from the near side kerb and 5 feet from the road surface.

In addition, an attempt was made to get an idea of the severity of glare produced by the various types of fittings at the selected observation position. For

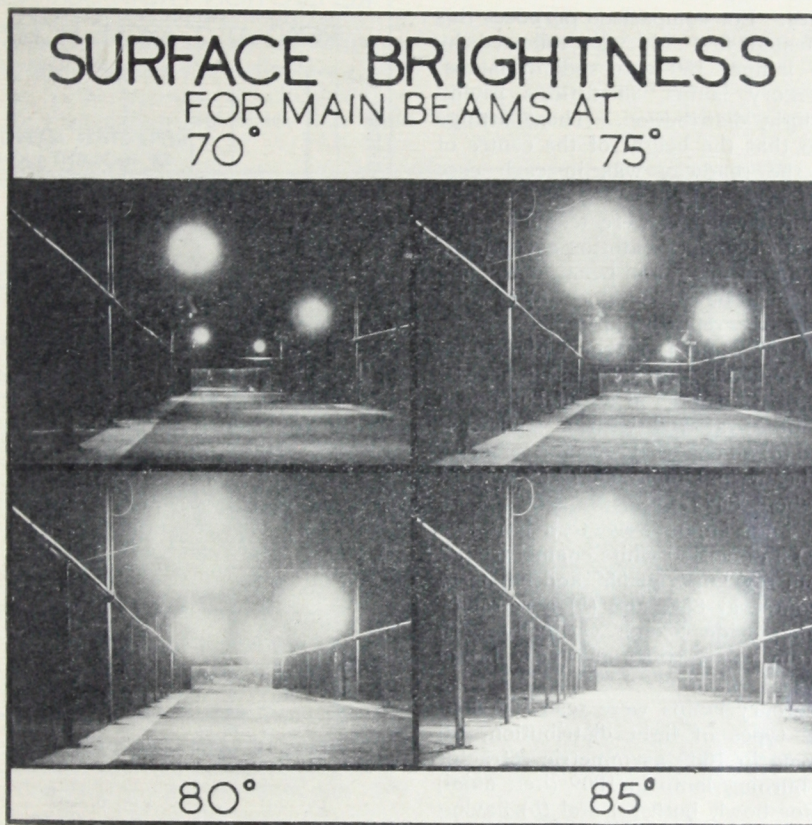


FIG. 4.

in the Westminster area placed at our disposal for this experimental work.

This street had an asphalt surface which, as a result of several years' service, had acquired a fair degree of polish—more particularly over the middle region. The experimental length embodied 5 lamp posts arranged in staggered formation at a uniform spacing of 153 feet: the width of the road over this stretch was sensibly constant at 38 feet 6 inches. Between the third and fourth lamps from one end, 15 regularly spaced spots were painted on the road

this test the lamp immediately above the observation position was switched off, and the test was carried out by placing a pair of photocells 5 feet from the road level and having their sensitive surfaces vertical and facing the test installation. A reading was taken of the light incident on the cells from the test installation, comprising the light received direct from the fittings and that reflected from the road surface and the sides of the houses. The direct light from the lamps was then cut off by suitable shields and a measure of the reflected light obtained.

By difference, the intensity of the light received direct from the fittings was deduced. Without any pretence of measuring the glare precisely, the ratio of the direct to the reflected light intensities is recorded as a glare index. In most cases this figure appears to run parallel with the glare effect actually experienced by observers, and as will be seen later, it does appear to be of some limited use in investigations of this nature.

The standard lighting of the experimental stretch of roadway was provided by 500-watt filament lamps in dome refractors mounted at a filament height of 23 feet 6 inches, in staggered formation, and overhung 1 foot 9 inches. For comparison purposes this installation was tested first: it was followed by 125-watt mercury lamps, 150-watt sodium lamps, and 400-watt mercury lamps, in fittings giving various types of light distribution. These fittings were suspended so that the height of the centre of the source from the roadway was in each case approximately 26 feet.

The 125-watt mercury lamps were tested in four types of fittings, (a) in smooth exterior asymmetric dome refractors giving a maximum beam at 75° and a rather wide vertical light distribution, (b) in prismatic axial asymmetric reflectors giving a beam maximum at about 65° and a rather wide curve, (c) in non-axial asymmetric silvered glass reflectors giving a "cut-off" of the source at about 80° and a strong maximum beam at 70° with a somewhat narrower beam, and (d) an enclosed reflector-refractor lantern giving a beam maximum at 72.5° with a virtual cut-off at about 85° .

The 150-watt sodium lamps were tested in two types of fittings, (a) an inverted white enamel trough giving a weak beam maximum at 55° and having a "cut-off" of the source at 85° , and (b) a refractor panel lantern giving wide beams vertically with maxima at 75° from the vertical and very broad beams horizontally.

The 400-watt mercury lamps were tested in lanterns giving three types of light distribution, (a) vertical burning lamp in 160° asymmetric refractor bowl, (b) vertical burning lamp in 180° (i.e., axial) asymmetric refractor bowl, both (a) and (b) having beam maxima at 75° with wide curves vertically and somewhat narrow ones in the 75° cone, and (c) horizontal burning lamp in a refractor panel lantern giving beam maxima at 75° and very broad beams horizontally.

The results are summarised in Table I and a few selected ones given in detail in Figs. 8–11.

In order to complete the data, the reflection of light from the road surface at an angle of 2° above the horizontal, from light incident at angles between 2° and 40° from the horizontal was measured. For these measurements a pair of photo-electric cells were mounted with their sensitive surfaces vertical, and with their centres at a height of $3\frac{1}{2}$ inches above

the road surface, i.e., at an angle of 2° from a spot on the road 8 feet away, towards which a parallel beam of light was directed at predetermined angles from a lamp carried on a pivoted arm. Readings were taken with the cells in line with the beam of light and with a 5° offset—the results are shown in Fig. 5 which again clearly indicates the strongly specular nature of the reflection when the light is incident at angles of less than 7° from the road surface.

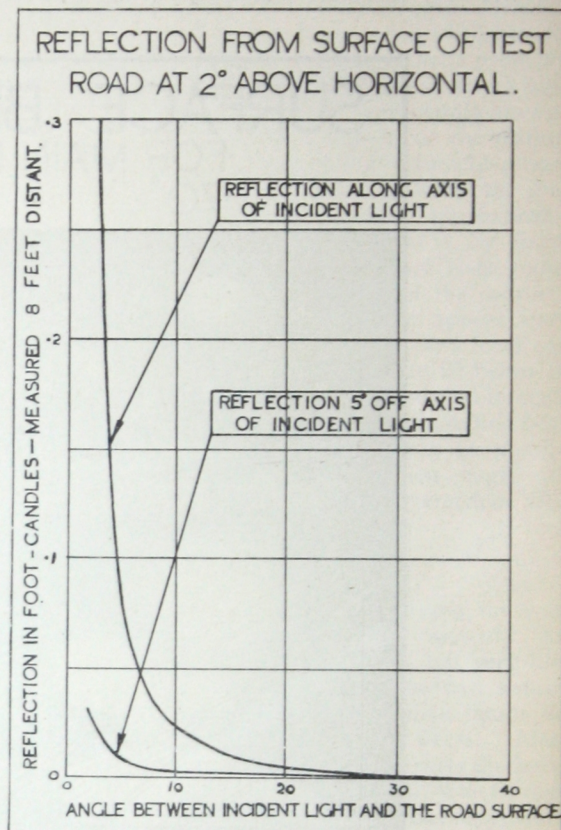


FIG. 5.

Discussion of Results

Considering first illumination values, it will be seen from Table I that the original 500-watt (8,470 lumen) filament installation gave test point readings of .117 f.c., i.e., a good Class "E" installation as assessed by the B.S. Specification 307. Although the diversity factor was as high as 21, it still appeared a very satisfactory and suitable installation. When 125-watt (5,000 lumen) mercury lamps were substituted, the test point illuminations fell in every case, and varied between .052 f.c. and .085 f.c., i.e., Class "F" installation. At the same time the

diversity ratios fell to between 7.5 and 11, due no doubt to the change in the shape of the light source and its consequent different light distribution.

On passing to the 150-watt (9,600 lumen) sodium lamps used in inverted enamelled reflector fittings the classification again rose to "E," with a diversity factor of 19, while in the refractor panel fitting the classification rose to "D," and the diversity fell to 7 to 1. Compared with the 125-watt (5,000 lumen) mercury lamps, the 150-watt (9,600 lumen) sodium lamps in the refractor panel fittings gave B.S. test point readings approximately three times as high with a rather better diversity factor. The appearance of the roadway was correspondingly improved.

The tests with vertical burning mercury lamps in both 160° and 180° asymmetric refractors, and horizontal burning lamps in panel refractor lanterns again brought the illumination into Class "D," the

.25 f.c., .40 f.c. and .21 f.c. respectively, and as shown by the isolux curves in Fig. 8.

The horizontal burning mercury lamps in refractor panel lanterns gave the highest general illuminations, the test point figures being .32 f.c. and .34 f.c., and fully one-half of the area of the whole roadway having horizontal illumination values between .32 f.c. and .50 f.c. (Fig. 10).

Visibilities

It may appear strange that in what has several times been referred to as quite good street lighting the visibility figures are not nearer to 100%, but these apparently low visibility figures are easily explained by reference to several factors which were operative throughout the whole series of experiments. In the first case, the projection on the disc was only



FIG. 6.

horizontal burning lamps giving the higher test point figures, viz., .32 f.c. and .34 f.c. In the case of the vertical burning lamps, the appearance of the road was very impressive, and was such as would immediately appeal to the members of a lighting committee or to technically-minded people who judged the lighting by appearance.

It must be admitted that in the case of town street lighting, appearances are of considerable importance and it may well be that this form of lighting would be regarded by the majority of people as highly satisfactory for this purpose.

Despite the relatively narrow light distribution in the 75° cone given by the vertical burning mercury lamp refractors, the illumination over the whole width of this rather wide road was quite satisfactory, as indicated by the three readings across the middle of the stretch used for illumination tests, viz.,

five inches square, and when this was viewed against the road surface as background at a distance of 153 yards it was not easy to pick out unless the contrast in brightness between it and the road surface was reasonably pronounced. Of course, detection became somewhat easier as the nearer test locations were reached: the nearest ones were 102 yards away. Secondly, as already mentioned, the road surface, due to its texture and to several years' wear, had a fairly well polished surface, and consequently, as shown in Fig. 5, it had fairly strong specular reflection properties. It was also cambered, perhaps a little more than is usual in modern roads, though it was not excessive. The height of the crown of the road was 9 inches above the level at the kerb, but this 9 inches drop was largely concentrated in the regions about 10 feet wide adjacent to the kerbs, with a result that light

incident on this area on the near side of the road was deflected from its course towards observers on the road and was directed towards the pavement. Consequently, from the standard observation position, 9 feet 6 inches from the near side kerb, this area looked dark, but it appeared bright when viewed from the pavement. Similarly, there was a strip of relatively dark road surface along the off side of the road, for here, with the 5 feet overhang adopted, there was no light behind this particular area that could be reflected towards the observer in the fixed position. Conditions in these two side lanes were rendered still worse by the presence of obstructions such as the sand-bin on the left and builders' material and dark railings and also a shop window with a dark blind on the right as may be seen in the daylight photograph of this section on the road (Fig. 6). As a result of this combination

filament installation with an overhang of 1 foot 9 inches, with that recorded for the four types of fittings using 125-watt mercury lamps with a 5-foot overhang. Taking the recorded visibilities for the installation as ordinarily used (i.e., column "b"—without shielding) for the 1 foot 9 inches overhang, it was 96% down the middle of the road and 38% down the near side lane. Averaging the results for the four 125-watt mercury lamp installations with 5-feet overhang, the visibilities down the middle are sensibly the same, namely, 96.5%, while down the near side lane the visibilities fall to 26.7%—a reduction of practically one-third. If the full 6-feet overhang as recommended in the Interim Report of the Ministry of Transport Committee on Street Lighting had been adopted, the visibility in this important region would have been still worse. It must also be remembered that these tests were all

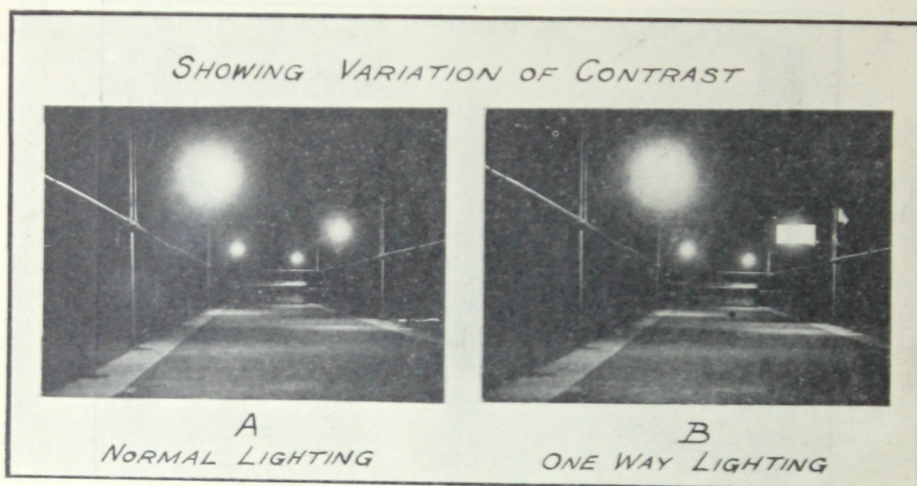


FIG. 7.

of circumstances, the visibilities as recorded for the near side and offside of the road were always much lower than the visibilities measured down the middle of the road. Practically always the visibility down the near side was less than that down the offside, and in view of the greater danger due to bad visibility here, it must be regarded as a serious defect in the systems of lighting investigated, but as it is present in every instance, it is obviously due to some fixed characteristic of the installations rather than to the types of lamps or fittings used. There can be no doubt that this bad visibility in this region is due primarily to the interaction of these three features: (1) 5 feet overhang, (2) fairly well polished surface, and (3) camber. Of these three, only one is under the control of the lighting engineer, viz., the overhang. The influence of this is shown quite clearly by considering the data recorded for the 500-watt

carried out when the road surface was dry; had they been carried out with wet surfaces and 5 or 6 feet overhang, the visibilities in this region would have been practically zero. Although it is not nearly so important, it is interesting to note that very similar visibility figures were obtained for the offside of the road—46% for the filament lamp with 1 foot 9 inches overhang, and an average of 33% for the 125-watt mercury lamps with 5-feet overhang. The conclusion is, therefore, forced upon us that in conditions similar to those of our tests, a small or no overhang is much preferable to the recommended 6-feet overhang.

On passing to the larger discharge lamps—sodium and mercury, one would expect the higher illumination values obtained to be accompanied by better visibility figures, but in some cases the response in this direction was disappointing. In the case of

the 150-watt sodium lamp in an inverted enamelled trough, the relatively low figure of 52% for the normal or unscreened visibility was perhaps to be expected since the illumination was very patchy and "pools of darkness" were present in between the

more strange still were the results obtained with the 400-watt vertical burning mercury lamps, for here, as already mentioned, the lighting of the roadway appeared well nigh perfect, and visibility measurements approaching 80% were expected, whereas an

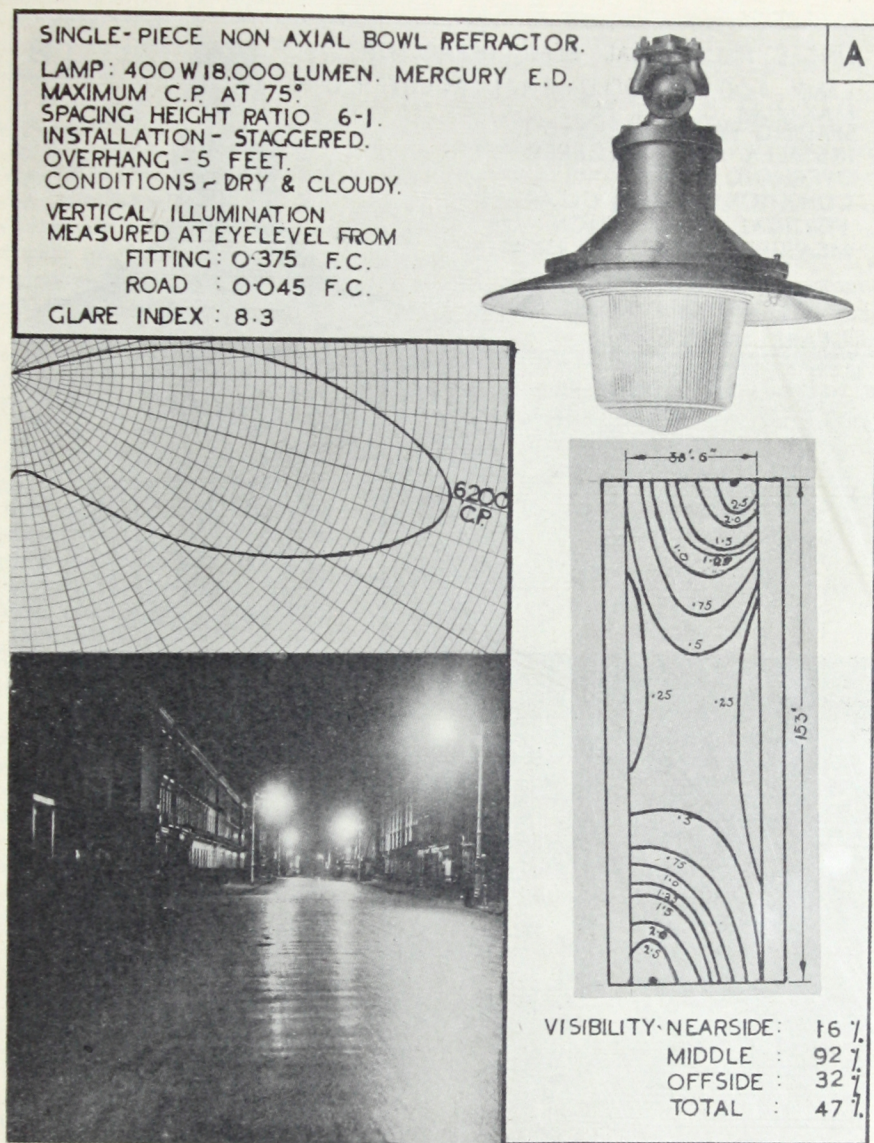


FIG. 8.

lamps, but with this same lamp in a refractor panel lantern giving a very good light distribution with test point figures slightly above .2 f.c. and a fairly high and fairly uniform road brightness, better visibility figures than 59% were expected. Even

average of only 47% was recorded for the fitting giving a 160° light distribution.

This low figure was due to the difficulties inherent in the test road already discussed, and to two others arising from the type of lighting—namely

(a) the 160° light distribution combined with the 5-foot overhang left the sides of the roadway somewhat dark, whilst the centre of the road was unnecessarily bright, and (b) the contrast between the brightness of the surface of the disc and the

at all, and it was possible to register only three correct readings out of 40 possibles at these four test points. Both these points are shown quite clearly by reference to the photograph (Fig. 8) in which the test disc—2 feet diameter with a 5-inch

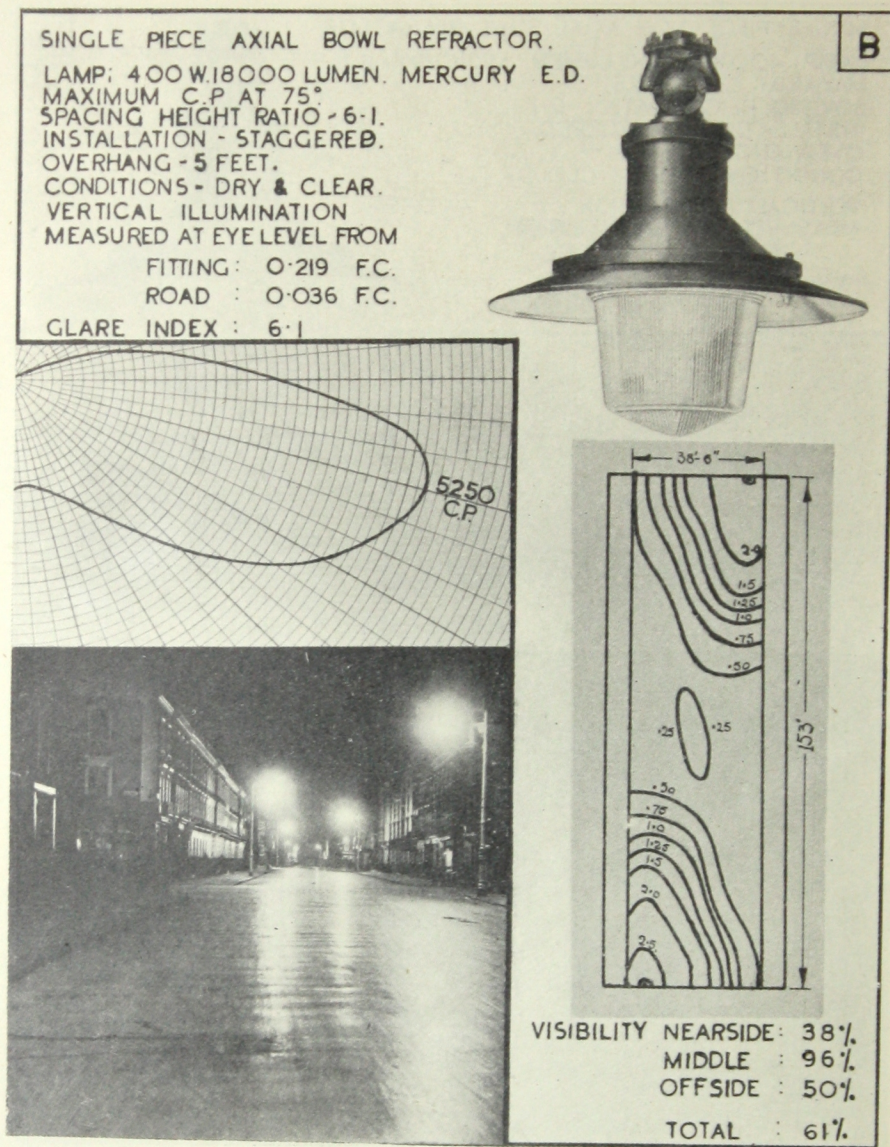


FIG. 9.

reflected brightness of the road surface was very low down both sides of the road. In fact, at three of the five test positions down the near side of the road and at one test position down the offside of the road, there was for practical purposes no contrast

square projection—stands on the middle test position in the near side of the road, i.e., 127 yards from the camera. Its practical invisibility indicates the reason for the average visibility over the five test points in this near side lane being only 16%. Along the

offside lane contrasts were a little better, but still disappointing, and the recorded visibility only rose to 32%. The discrepancy between these recorded visibilities with an average over the whole of the test area of 47%, and the very good appearance of the road when looked at without any critical examination requires an explanation. A possible reason for this appears to be as follows. The roadway and the houses had such a large volume of light thrown on them that details were being seen by direct vision. Such a state of affairs was, of course, excellent for town street lighting and from the pedestrian's point of view, but such conditions were difficult for the motorist who wanted to see obstructions in silhouette. As a result, there were positions along the roadway when direct vision was just changing to silhouette vision, and at such points, due to their brightness, objects became temporarily invisible. This argument will be developed later when dealing with arterial road lighting fittings.

In order to try to overcome the relatively dark lanes along the sides of the carriageway while still maintaining the 5-foot overhang and excellent lighting down the middle of the road, a refractor giving an axial (i.e., 180°) asymmetric light distribution was tried (Fig. 9). Although lack of contrast was still present, it was not so pronounced as with the non-axial asymmetric (160°) fittings. Along the near side lane the visibilities rose to 38%, as compared with 16% formerly—and along the offside lane they rose to 50%, compared with 32% for the non-axial fitting. With a visibility of 96% down the middle of the road, these gave an average figure of 61%—a distinct improvement on the 47% recorded with the non-axial fitting. Taking this figure in conjunction with the 62% recorded for 150-watt sodium lamps, and 67% for horizontal burning mercury lamps in axial fittings, it appears certain that even on wide roads, if a 5 or 6-foot overhang is adopted, better visibility is obtained by using axial fittings than by using non-axial (160°) fittings, more particularly as this increased visibility is largely due to an improvement in that most important near side lane.

It is worthy of note in passing that horizontal burning mercury lamps in refractor panel lanterns, besides giving a better spread of illumination across the roadway and higher test point figures than either of the fittings using vertical burning lamps, also gave higher visibility readings (67% against 47% and 61%)—possibly due to the better light control in the vertical plane, and to the much wider beam spread horizontally (Fig. 10).

Glare

The effect of glare was measured directly by taking visibility readings with the light sources exposed and with screens interposed between them

and the eyes. In this way a direct measure of the reduction of visibility due to glare was obtained. In considering these figures, it must be remembered that in refractor fittings—which are sometimes accused of causing glare—definite attempts had been made to limit the main beam to 75° from the vertical, and as far as possible to give a virtual cut-off above this angle—conditions which were shown in the first part of this paper to represent the best compromise between road surface brightness and glare. Even in the refractors housing vertical burning mercury lamps, light controlling elements were embodied tending to limit the amount of light emitted at angles above 75°.

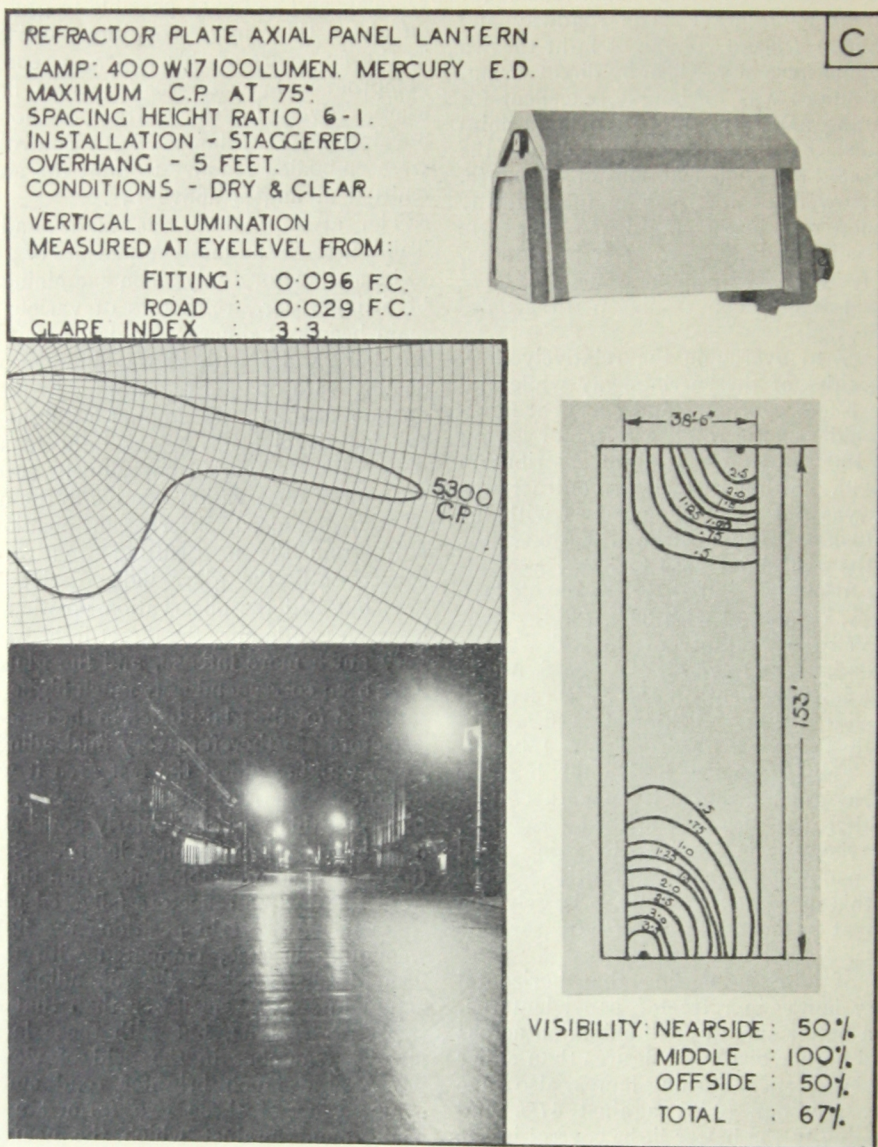
The attempt that was made and recorded in Table I, to get an indirect measure of glare, appeared to be satisfactory only when examining similar types of fittings, e.g., refractors of various types giving main beams at different angles, but it failed to give parallel results with those obtained visually when dealing with opaque reflectors. In the case of such opaque fittings, the amount of light reaching the eye for visual tests, or the light sensitive cells for physical tests, varied enormously according to the position of observation relative to the nearest fitting. At our standard observation position, the direct light from the next fitting was very small, and consequently the glare index derived from it was low, but had the observation position been halfway between two lamps, the direct light would have been very much more intense, and the glare index would have been correspondingly much higher. The figures recorded for the glare index in the case of the opaque reflectors are therefore very misleading.

On walking along the test area it was found that in no case was the glare oppressive or even uncomfortable—this was particularly noticeable in the case of the horizontal burning lamps. Strange to say, the most uncomfortable units from this point of view were the opaque reflectors (silvered glass and white enamel). At certain positions the light from them was quite intense, compared with the dark background surrounding the offending source. The actual intensity was lower than that received from refractor lanterns, but with these latter there was always a number in the field of view. They also produced a much brighter road surface, and the combination of these two formed a kind of light background against which the nearest unit stood out, but not so prominently as did the opaque reflector unit against a black background.

In addition to this unpleasant contrast between the brightness of the source and its background, in the case of opaque fittings, the constantly varying nature of the glare was disconcerting. At a position level with one lamp post glare was almost absent, but on passing to the mid-zone it became very

oppressive, and on passing to the neighbourhood of the next lamp glare again became negligible. The eye, therefore, never had a chance of settling down to any particular set of conditions, but was being called upon to adapt itself to constantly changing

silvered glass reflector gave the biggest reduction in visibility due to glare (9%) shown by any fitting that was tested. It is rather curious that some installations gave a little better visibility (up to 3%) when the units were exposed than when they were



not materially increased by shielding the eyes from the units, it must be admitted that such shielding did make looking down the road easier on the eyes; this was particularly noticeable in the case of units that gave much light above the 75° line.

available used to give the best possible results from the point of view of the motorists. The problem engineers have to meet will probably be further simplified in the not very distant future by the adoption of two unidirectional tracks separated by

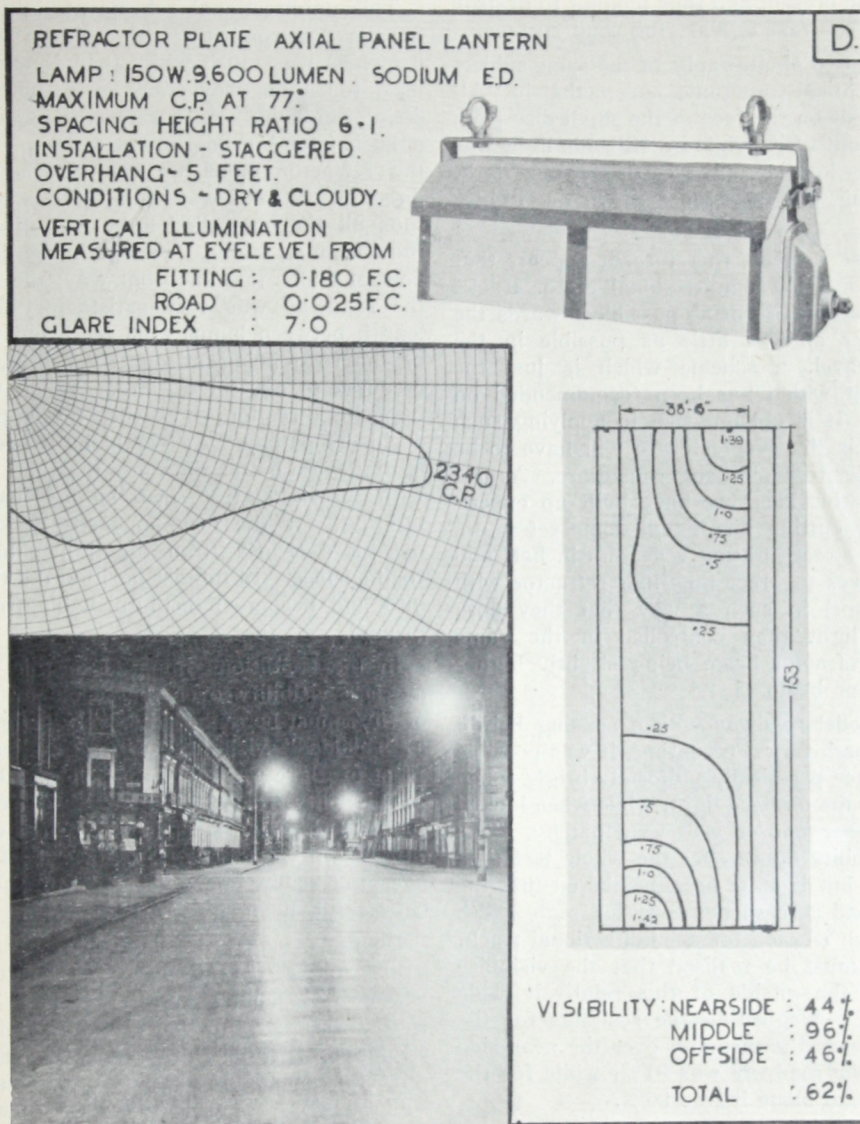


FIG. 11.

Motor Road Lighting

There is one further aspect of this matter that deserves consideration. In the case of motor roads, pedestrian traffic can be neglected, and the light

a grass verge as has already been done in some cases here, and in more cases on the Continent. As has already been pointed out, only the light that is reflected by the road towards the motorists and at quite low angles, is any use in building up relatively

bright road surfaces; consequently, any light that is emitted by the lantern in the same direction that the motorist is travelling is wasted from the point of view of assisting vision. It is, in fact, worse than wasted since it actually helps to make vision more difficult by lighting up the face of any obstruction that may be present and thus tending to destroy the brightness contrast against the road surface.

Fig. 7 shows two photographs of the same subject taken under identical conditions, except that in "A" light was incident on the face of the small disc from the fitting in front of it, while in "B" this light was obstructed, thus keeping the face of the disc dark, and emphasising the contrast against the lighter roadway.

For both these reasons, therefore, it appears that the fitting for lighting unidirectional motor tracks should direct as much light as possible towards the oncoming driver and as little as possible in the direction of travel, a scheme which is just the opposite of that which has been recommended on the Continent. It is obvious that in applying such a scheme as this the greatest care will have to be exercised in order to avoid dangerous glare. As one embodiment of this idea¹ we have built up experimental units by cutting directional dome refractors and directional street lighting reflectors in half and putting the halves together (one half refractor with one half reflector) in such a way that they both projected the light they controlled in the same direction, the refractor beam being slightly higher than the reflector beam.

Using the model roadway with a spacing height ratio of 6 to 1 and central mounting, it was possible to get the surface practically uniformly bright when observed facing the directed light, while when looked at from the other end it was very patchy. The percentage visibility figure over the whole test area was only 54%, but it must be remembered that the experimental road corresponds to a full scale width of 35 feet, which is wide for a unidirectional track, and further it must be realised that the visibility recorded down the offside of this relatively wide road was "nil." Neglecting the readings for the offside of the road, the visibility over the near side and middle of the roadway was 81%, while for the middle of the road alone it was 96%.

To use such a fitting as this for motor road lighting it is necessary to arrange the fitting and the spacing height ratio so that the light is directed to give a relatively uniform road brightness right up to or even a little beyond the foot of the next post. This can be done without producing excessive

glare if the spacing height ratio does not exceed 6. For a standard spacing of 150 feet, it would be better, but not essential, to raise the height of the source to approximately 30 feet, while for a spacing of 125 feet the height of 25 feet would be perfectly satisfactory.

This unidirectional scheme of lighting was tried on the test roadway, although its width (38 feet 6 inches) was much wider than is ever likely to be used for a one-way track of a motor road. The fitting employed was a refractor panel lantern with a horizontal burning mercury lamp; and in which the refractor panel on the side away from the direction of travel was replaced by a reflector panel, thus all the controlled light was directed towards the oncoming traffic. Viewed in the direction of the flow of traffic (assumed one-way) the appearance of the roadway was very satisfactory—even the full length between lamps (153 feet) and the full width of the road being adequately bright, and without recourse to excessive glare. When viewed in the opposite direction, however, the appearance was decidedly patchy. As would be expected, visibility figures were better than any that had been obtained with previous test installations using two-way lighting, for the disc appeared darker and stood out more clearly from the lighter background of road surface. In no test position did the disc merge into and become indistinguishable from the background.

In the conditions imposed in this test road an average visibility over the whole of the test area of 75% must be regarded as very satisfactory, while a "shielded" visibility of 77% indicates that the effect of glare was quite negligible. On considering the visibility figures down the three test lanes, i.e., 76% on the near side, 98% down the middle, and 50% down the offside, it is clear that the visibility over the really important area of the roadway is better still, being no less than 87%.

By the courtesy of the Brighton Lighting Company and the Lighting Engineer to the Hove Borough Council, we were fortunate in being able to try this scheme on a two-track bypass road (Hangleton Road). In this case, the units were again refractor panel lanterns, but this time using 150-watt sodium lamps. The lamps were mounted "in line" over each track, and had an overhang of 6 feet from the central island kerb. The refractor panel away from the direction of traffic was again replaced by a reflector giving a virtual cut-off at 12° on the far side of the fitting. The appearance of the road in the direction of travel was very good indeed, while the contrast between the road surface and the test disc was most pronounced, as is shown in Fig. 12.

¹ Prov. Pat. No. 9621/37.

Visibility readings were 100% down the near side lane, 100% down the middle, and 54% down the offside. The readings down the offside lane would have been much better but for the fact that at certain

near side and middle 100%. The three sets of tests —on the 1-5th scale model road, on the street in town, and on the bypass road—conclusively prove that for the one-way tracks of dual roadways

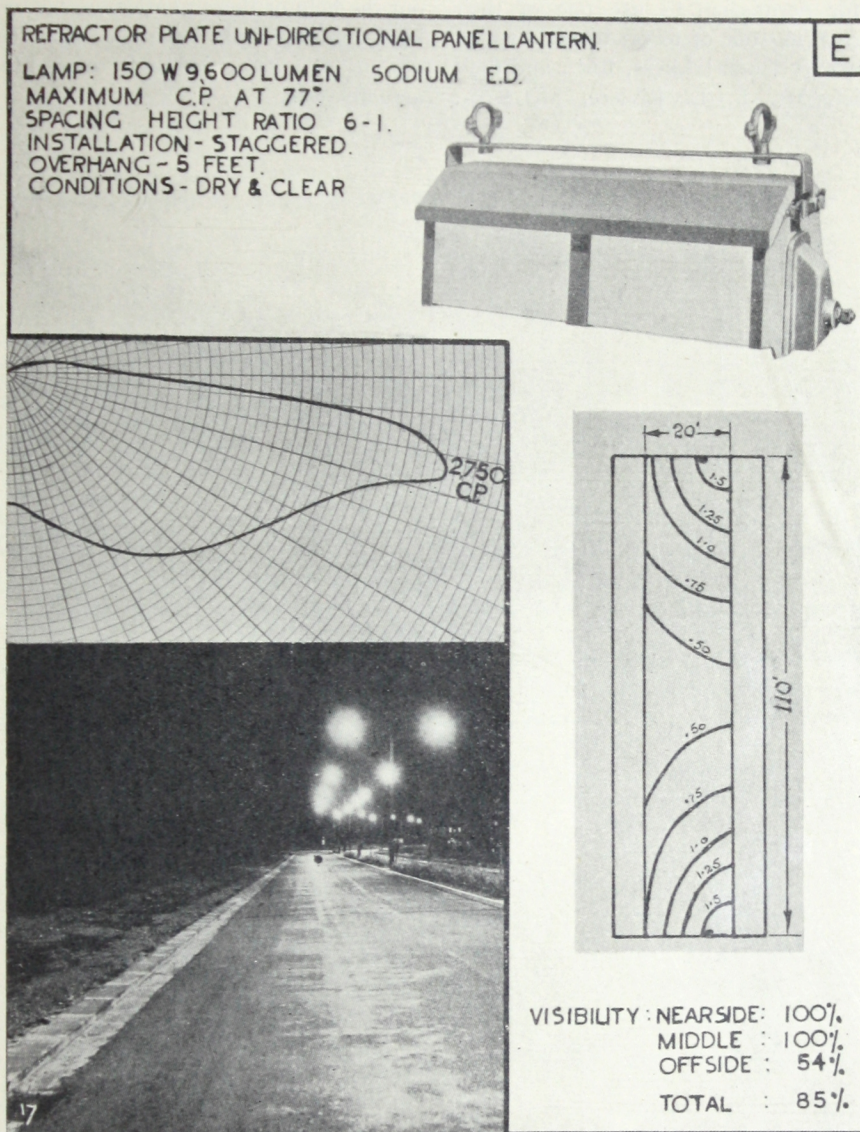


FIG. 12.

"times" the projection on the disc was lost in the background formed by the hedge growing along the centre island, but even so, the average visibility over the whole test area was 85%, and over the

unidirectional lighting, with the light suitably controlled and directed towards the flow of traffic, produces perfect visibility from the motorist's point of view.

In conclusion, we would like to acknowledge, with grateful thanks, the enormous amount of help we have received in the accumulation of the data embodied in this paper. We would like to render our special thanks to the Westminster City Council and their City Engineer, Mr. J. Rawlinson, M.Eng., M.Inst. C.E., for permission to use one of their streets for the carrying out of tests; to the London Associated Electricity Undertakings, Ltd., and their Engineer-in-Chief, Mr. P. L. Riviere, M.I.E.E.,

for permission to use the lamp standards, and for their undertaking free of charge the installation of the various fittings that were tested; to Mr. M. F. Pyser, Public Lighting Engineer, for the very great interest he took in the work, and for arranging the detail work involved in the test installations. Without the help of these gentlemen, we feel that such an investigation would have been practically impossible or, at any rate, infinitely more difficult than it actually was.

TABLE I.

ESSENTIAL DATA DERIVED FROM TESTS

Staggered Arrangement.

Spacing 153 feet.

Height 26 feet.

Overhang 5 feet.

LAMP AND FITTING.	500 w. Filament 160° Dome refractor.	125 WATT H.P. MERCURY.				150 WATT SODIUM.	
		180° Prismatic reflector	160° Silvered reflector.	160° Reflector- refractor.	160° Dome.	Enamelled Trough.	Prismatic Panels.
ILLUMINATION DATA—							
Angle of max. beam ...	72 5°	65°	70°	72.5°	75°	55°	77°
Cut off ...	Virtual	Virtual 85°	Absolute at 90° Virtual abt. 85°	Virtual	Virtual	85°	Virtual at 90°
Test Pt. Ill'n (f.c.) {	.117	.080	.085	.076	.074	.13	.201
Diversity ratio ...	.117	.078	.070	.052	.080	.14	.206
	21	8.7	11	7.5	10	19	7
% VISIBILITY—	(a) (b)	(a) (b)	(a) (b)	(a) (b)	(a) (b)	(a) (b)	(a) (b)
Near side (a) {	44 38	26 26	42 24	30 24	34 32	32 13	41 44
Middle (b) {	80 96	96 96	96 98	98 98	94 94	94 96	94 96
Offside (b) Not {	48 46	50 36	36 24	34 34	54 38	38 34	40 46
Av. full width {	57 60	57 53	58 49	54 52	61 55	55 52	59 62
Reduction in visibility due to glare (a-b) ...	3% (increase)	4%	9%	2%	6%	3%	3% (increase)
GLARE INDEX—							
Direct light from fittings	.104	.057	.006	.059	.064	.003	.180
Reflected light from road and houses ...	.010	.011	.004	.010	.006	.0015	.025
DIRECT—Reflected ...	10.4	5.2	1.5	5.9	10.7	2	7
REMARKS... ..	Overhang 1' 6" only	No contrast at 2 points	No contrast at 3 points	No contrast at 1 point	No contrast at 3 points	No contrast at 3 points	

LAMP AND FITTING.	400 WATT MERCURY.			EXPERIMENTAL MOTOR ROAD LANTERNS.	
	Vertical— non-axial refractor.	Vertical— axial refractor.	Horizontal— refractor panels.	Horizontal— 400 watt Mercury.	150 watt Sodium.
ILLUMINATION DATA—					
Angle of max. beam ...	75°	75°	75°	75°	77°
Cut off ...	—	—	Virtual	Virtual	Virtual
Test Pt. Ill'n (f.c.) {	.240	.272	.32	.17	.40
Diversity ratio ...	.194	.252	.345	.24	—
	13	9.1	10	17	4
% VISIBILITY—	(a) (b)	(a) (b)	(a) (b)	(a) (b)	(a) (b)
Near side (a) {	18 16	44 38	60 50	74 76	— 100
Middle (b) {	88 92	94 96	100 100	100 98	— 100
Offside (b) Not {	28 32	60 50	56 50	56 50	— 54
Av. full width {	44 47	66 61	72 67	77 75	— 85
Reduction in visibility due to glare (a-b) ...	3% (increase)	5%	5%	2%	—
GLARE INDEX—					
Direct light from fittings	.375	.219	.096	.122	—
Reflected light from road and houses ...	.045	.036	.029	.030	—
DIRECT—Reflected ...	8.3	6.1	3.3	4.1	—
REMARKS	No contrast at 5 test points (4, 6, 7, 10 and 12)	One test point (No. 10) gave practi- cally no contrast			

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